THE INTERFERENCE OF ELECTRICAL PLANT WITH THE RECEPTION OF RADIO BROADCASTING.

By A. MORRIS, Member.

(*Introductory remarks to a discussion before the* WIRELESS SECTION, *22nd November*, 1933.)

INTRODUCTION.

In the engineering development of radio broadcasting services an outstanding difficulty on the reception side has been that of electrical interference. The following notes deal with the interference arising from the operation of electrical machinery.

GENERAL FEATURES CONCERNING INTERFERENCE FROM ELECTRICAL PLANT.

Any item of electrical plant in which the operating current is suddenly varied or interrupted, either intentionally or as a feature of its functioning, will sustain a change of potential of one portion of the circuit with respect to another portion, or with respect to earth. In such circumstances an additional or parasitic electric current will flow in the system. A large number of items of electrical plant appear to produce such an effect even when satisfactorily performing the work for which they are designed.

Such currents give rise to interference with radio reception by producing audible noise at the loud-speaker or headphones in the case of a sound transmission, or by mutilation of the picture in the case of television. The interference may be general over the whole of the broadcasting wave-band, or alternatively it may be much more pronounced over one portion than over another. The characteristic sounds produced by a number of items of plant* have been recorded by the Gramophone Co., in co-operation with the Post Office Engineering Department, for servicing purposes.

RADIATED AND CONDUCTED TYPES OF INTERFERENCE.

Interfering currents arising in the manner outlined above are capable of widespread propagation. The type of interference known as "radiated interference" may either be directly radiated from the source or reach the receiver as mains-borne radiation. The interfering range of the mains-borne component is in general much greater than that of the directly radiated component.

In certain cases interfering currents are transmitted along the supply mains and fed into the radio receiver along with its normal power supply. The resulting disturbance is known as "conducted interference." Such interference is seldom severe in a modern receiver when arising from the passage of currents of radio frequency.

AURAL SIGNAL/NOISE RATIO.

In any communication system the degree of freedom from interference depends upon the relative strengths of the desired signal and of the disturbance. This signal/noise ratio is of fundamental importance in all communication systems, including broadcasting systems.

The Technical Secretariat of the I.E.E. Committee on Electrical Interference with Broadcasting has had a gramophone record prepared for the purpose of demonstrating aurally the effect of various values of signal/noise ratio ranging from zero to + 40 decibels. The record was made by the Gramophone Co. and is the property of the British Broadcasting Corporation. Different types of programmes were used in its preparation, together with various interfering sounds such as steady notes at different frequencies as well as the noises common to communication systems. Opinion based upon this record appears to indicate that for concert material, subject to continuous noise, a signal/noise ratio of + 40 decibels is necessary for the purpose of ensuring high-quality reception.

RADIO SIGNAL AND INTERFERENCE LEVELS.

With the present international restrictions in regard to the power of medium-wave and long-wave transmitters, and owing to the increasing use of ultra-short waves of low power, the actual level of the radio interference from electrical plant is required to be relatively low in order to ensure services with a satisfactory aural signal/noise ratio.

TABLE 1.

Lower Limit of Useful Signal Field for Broadcasting Services on Various Wave Ranges.

Wave range	Lower limit of useful signal field
Below 20 m	10 μV per metre ($\equiv$ + 20 decibels on 1 μV per metre)
20 to 200 m	20 μV per metre ($\equiv$ + 26 decibels on 1 μV per metre)
200 to 2 000 m	1 mV per metre ($\equiv$ + 60 decibels on 1 μV per metre)

The figures contained in Table 1 may be regarded as representing the lower limit of useful signal field for broadcasting services on various wave ranges. When read in conjunction with a suitable value for signal/noise ratio, they convey a quantitative idea of the degree to which it is desirable that the general level of radio noise from electrical plant should be controlled.

The actual level of the noise in any particular locality is usually rather difficult to measure, especially in situations close to interfering sources. As an actual example of the level of interference from a particular item of plant, however, and in order to supplement

* The interfering noises from a number of items of electrical plant were demonstrated at the meeting—aurally by means of a radio receiver, and visually by means of a cathode-ray oscillograph.

the use of Table 1, the results of measurements made at a distance of 15 yards from a 132-kV transmission line

TABLE 2.

Magnitude of the Measured Level of Interference at 15 yards from a 132-kV Transmission Line.

Wavelength	Interference level, in decibels on 1 μV per metre	
	Dry condition	Wet condition
15 m	− 16	+ 2
20 m	− 12	+ 8
200 m	+ 16	+ 42
2 000 m	+ 30	+ 58

on dry and wet days respectively are reproduced in Table 2.

COMMERCIAL CLASSIFICATION OF INTERFERING ITEMS OF PLANT.

For convenience in dealing commercially with electrical plant, from the radio-interference point of view, the items have been classified as:—

A (i). Domestic apparatus.
(ii). Small commercial apparatus.
B. Large commercial plant.
C. Traction apparatus.
D. Automobiles and aircraft.

The items included in each of the above classes are set out in Appendix 1.

PARTICULARS OF THE INTERFERENCE FROM THE PRINCIPAL TYPES OF PLANT.

Experience to date of this aspect of the subject is summarized in Appendix 2. It will be seen that all the items referred to give rise to direct and mains-borne radiation, except of course the spark-ignition systems of automobiles and aircraft, from which the radiation is wholly direct. Furthermore, the interference from such systems is usually confined to short-wave and ultra-short-wave services.

METHODS OF ENSURING FREEDOM FROM ELECTRICAL INTERFERENCE.

(*a*) *Suppression at the source.*

In the case of definitely interfering types of plant, freedom may be obtained by the application of suppressive measures to such plant, whereby the parasitic currents are restricted in such a manner as to prevent their propagation from the source, either as direct or as mains-borne radiation. The suppression devices required for this purpose may be embodied in the plant during its design and manufacture, thus ensuring the equivalent of a non-interfering type. Alternatively, the suppressors may be added subsequent to installation and initial operation of the plant.

The advantage of suppression at the source lies in the immunity thereby conferred upon all radio receivers within, or liable in the future to come within, the disturbing range of such source.

In those instances where the disturbing currents reach the radio receiver by radiation to, and pick-up on, the aerial system, and where practicable modifications of this system are without effect upon the signal/noise ratio of the receiving system, suppression at the source is the only cure. Electric traction systems, of which the trolley-bus is a notable example, as well as the spark-ignition systems of automobiles and aircraft, fall within this category.

(*b*) *Ameliorative measures at the radio receiving station or at the radio receiver.*

Failing action at the source, ameliorative measures may in certain instances be taken at the receiving station or at individual radio receivers.

PRINCIPLES UNDERLYING THE DESIGN OF SUPPRESSORS AND OF OTHER AMELIORATIVE DEVICES.

(*a*) *Suppression at the source.*

The methods involve the use of resistances or of choke coils for reducing the magnitude of the currents, and of earthed condensers for by-passing them to earth. These items are required to be used sometimes separately, and at other times in combination. Electrical screening is sometimes also necessary, but when employed it should be as complete as possible.

Appendix 3 gives technical particulars of various suppression devices. Figs. 1 to 12 show their circuit arrangement.

(*b*) *Ameliorative measures at the radio receiving station or at the radio receiver.*

Such ameliorative measures as may be taken at the receiving station or at the receiver are of necessity limited to the control of all interference other than that which is actually picked up by the aerial. In this connection the term "aerial" is to be understood to exclude the transmission system which connects it to the radio receiver.

Choke coils and earthed condensers inserted in the incoming power supply and located at or near to the main switch of the receiving station will considerably restrict the flow of disturbing radio currents in the internal wiring of the premises, thus limiting local radiation and thereby interference pick-up by the aerial as well as the magnitude of the currents directly conducted to the receiver via its power supply. Such devices are referred to as mains filters. If, in addition, the internal wiring of the premises is enclosed in efficiently earthed conduit, the radiation effect of any residual currents carried by such wiring will be reduced.

The elevation of the aerial and the use of a screened lead-in is beneficial when the aerial can be elevated to an extent which will place it outside the effective range of intense local radiation. Special screening methods, involving tuned impedance-matching circuits in conjunction with single- or double-wire transmission lines, are desirable in this case in order to minimize loss of signal strength. In those cases where the loss of signal strength, consequent upon the use of such methods, necessitates the operation of the receiver at relatively

high sensitivity, the accompanying increase of receiver background noise may prove disadvantageous.

Even with screened receivers and specially-designed transmission lines, elimination cannot be effected unless the aerial can be placed outside the field of interference. The application of these means is, however, of special value in some cases, especially where the cost of their elaboration is justified.

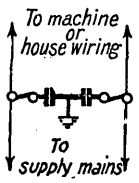

FIG. 1.

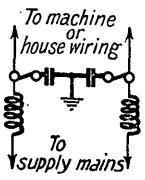

FIG. 2.

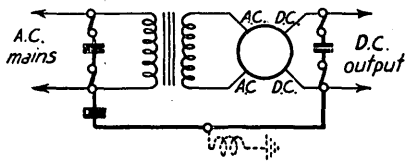

FIG. 3.

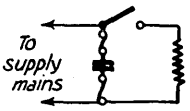

FIG. 4.

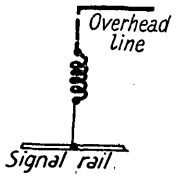

FIG. 5.

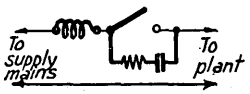

FIG. 6.

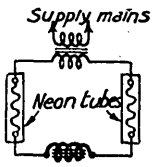

FIG. 7.

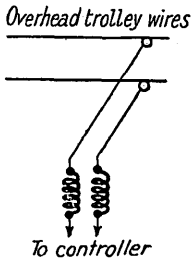

FIG. 8.

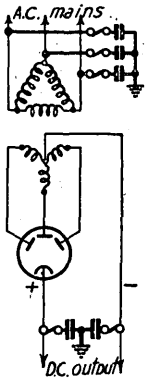

FIG. 9.

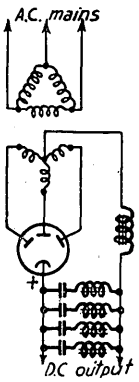

FIG. 10.

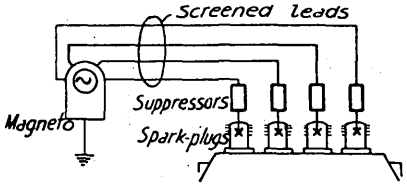

FIG. 11.

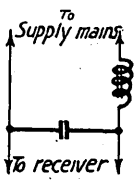

FIG. 12.

COST OF INTERFERENCE SUPPRESSORS.

The cost of incorporating suppressors during the manufacturing stage, in the various items of domestic and small commercial plant (see Appendix 1, Sections 1 and 2), has been approximately computed. The costs are such as to increase the retail price of the item by from 1 to 8 shillings. In a few instances re-design of the items would be beneficial from the point of view of simplification of the suppressor and of its housing.

In regard to large commercial plant (see Appendix 1, Section 3), the cost will be governed considerably by the cost of the choke coils, in those cases where such chokes constitute the basis of the suppressor. A manufacturing cost of from 5s. to £2 per coil would apply to 600-microhenry chokes, suitable for currents of from 5 to 50 amperes respectively. Available figures indicate that for the suppression of the audio-frequency harmonics, up to and including the 24th, of mercury-arc rectifier systems, the retail price per kW is from 6s. to 5s. for rectifiers of from 1 000 kW to 2 500 kW output respectively.

So far as traction systems are concerned (see Appendix 1, Section 4), a pair of choke coils suitable for trolley-bus systems, in which the starting current is of the order of 300 amperes, costs from £12 to £16.

Suppressors for the ignition systems of automobiles and aircraft are not yet in general use, neither is the demand very great. The present-day price of such suppressors and of complete screening systems is probably much higher than it will be in the future.

GENERAL POSITION IN REGARD TO RADIO INTERFERENCE.

Electrical interference with broadcasting has been experienced in all countries which have shared in the

scientific and commercial development of electrotechnics, and particularly in those countries where electricity has been extensively applied for domestic and industrial purposes.

The Wireless Telegraphy Acts of this country do not deal with the matter of electrical interference, and the electrical operating companies and other owners of electrical plant are accordingly in a position to repudiate liability for disturbance to broadcast reception. A similar position has existed in a number of other countries. The present tendency, however, is in the direction of placing responsibility for the avoidance of interference upon the user of electrical plant, and various laws and decrees have been enacted in certain countries in order to secure this object.

The subject of electrical interference has also been considered at conferences of the International Telegraphic Union and of the International Electrotechnical Commission. Each of these bodies has recommended that steps be taken to render electrical plant free from the susceptibility of causing interference.

In this country the Institution has set up a committee* to study the matter and to make recommendations to the Council.

Assistance Afforded to Broadcast Licensees in This Country.

Although the Postmaster-General has no statutory power under which he could compel owners to suppress interference from electrical plant, the Post Office undertakes to assist the public in the elimination of electrical interference with broadcasting. The British Broadcasting Corporation fully co-operates in this matter. Complainants of electrical interference with broadcasting are furnished by the Post Office with a questionnaire, which, when completed, provides full information for the subsequent investigation of the complaint. A copy of this questionnaire will be found in Appendix 4. It is available on request at all post offices throughout the country. All complaints of interference received from licensees, either directly or via the B.B.C., are investigated by the Post Office Engineering Department and the interference is traced to its source. On receipt of permission from the owners of interfering plant, a cure is demonstrated and particulars furnished as to the method of fitting the appropriate suppression device. Difficulties are sometimes met with in regard to the adoption of the cure. One main and usual difficulty is that of incidence of the cost. The owners are first approached on this matter, but, at times, it is necessary to attempt settlement on the basis of a contribution from all the parties concerned, or from the complainants only. Numbers of interference cases are satisfactorily completed, but numbers remain unsettled because of the inability to reach agreement on this matter.

Conclusion.

Experience indicates that the amount of radio interference is becoming greater and its distribution more widespread. There is believed to be a large body of persons which, for one reason or another, has not yet registered its dissatisfaction. There are districts in which electrical interference has existed for many years; many licensees in such districts have no knowledge of the possibilities of suppression, whilst numbers of other persons refrain from becoming licensees on account of the prevailing conditions.

As has already been pointed out, the radio engineer can ameliorate particular interference conditions at the radio receiving-site, but the general level at any particular locality of interference from electrical machinery can be controlled only at the source. This control, which is in the hands of those responsible for the plant, presents no outstanding difficulty, since the fundamental technique of this subject, as indicated above, is relatively simple. The present-day problem of electrical interference is in fact not primarily an electrical one, but consists of the reconciliation of the economic aspects of the various interests.

* See *Journal I.E.E.*, 1933, vol. 73, p. 93.

APPENDIX 1.

Commercial Classification of Interfering Items of Plant.

(1) *Class A* (i). *Domestic apparatus.*

Fans; vacuum cleaners; refrigerators; sewing machines; washing machines; floor polishers; hair driers; heating pads; electric bells; electric clocks (contactor type); high-frequency medical apparatus ("violet ray"); electric wiring; vibrators (body and face); water heaters (thermostatically controlled).

(2) *Class* A (ii). *Small commercial apparatus.*

Refrigerators; dough mixers; ice-cream machines; sausage machines; coffee grinders; dental drills; hair driers and clippers; paint sprayers; cash registers; calculating machines; incubators (egg and bacteriological); vibrators (body and face); cream or oil separators; petrol pumps.

(3) *Class* B. *Large commercial plant.*

Motors; generators; rotary rectifiers; flashing signs (motor-driven and contactor type); traffic signals (motor-driven and contactor type); lift motors and contactors; oil-burner motors; thermostatic signs; vibrating-reed rectifiers; telephone switching apparatus; incubators (10 000-egg); static rectifiers (mercury-arc or valve); neon signs; diathermy apparatus; ultra-violet-ray lamps; dust precipitators; overhead high-tension transmission lines.

(4) *Class* C. *Traction plant.*

Trams; trolley-buses; electric railways; railway signalling systems.

(5) *Class* D. *Automobiles and aircraft.*

Petrol engines with coil and/or magneto ignition.

APPENDIX 2.

PARTICULARS OF THE INTERFERENCE FROM VARIOUS TYPES OF ELECTRICAL PLANT.

Type of interfering electrical plant	Type, and range, of the interference	Remarks
(*a*) Motors of both d.c. and a.c. types	Is chiefly of the radiated type, though much of it is mains-borne. Is usually inappreciable beyond a range of 200 yards.	Includes small totally-enclosed motors for domestic use as well as the larger commercial types of motors. Alternating-current induction motors in general give little interference.
(*b*) Generators of both d.c. and a.c. types	May be of the radiated and directly-conducted (audio-frequency) types. Much of the radiation is mains-borne. Is usually inappreciable beyond a range of 200 yards.	Includes rotary convertors. Commutator sparking is not an essential feature of interference from motors and generators.
(*c*) Rectifiers of the commutator type	Consists principally of direct radiation from the plant, including the batteries undergoing charge. Is very severe up to a range of 200 yards. The mains-borne radiation is small in comparison with the direct radiation.	Used for battery charging and for cinema arcs.
(*d*) Vibrating-reed rectifiers; flashing signs of various kinds, including road and railway control signals; telephone switching plant; electric bells, ovens, heating pads, and other forms of thermostatically-controlled plant; also electric tramway and lift controllers	Consists principally of mains-borne radiation. Has a range up to 100 yards.	
(*e*) Neon signs	Is of the radiated type, both direct and mains-borne. Has a range of about 200 yards in the high-frequency type of sign and about 50 yards in the low-frequency type.	Includes the high-frequency (indoor) type as well as the more common low-frequency (outdoor) type.
(*f*) Lift plant	Is of the radiated and directly-conducted types. The influence of the direct radiation extends up to about 25 yards.	Includes the motor and controller and trailing cables. Lift motors of the d.c. type generally cause more severe interference than those of the a.c. type.
(*g*) Tramway and trolley-bus systems	Is of the radiated type. Much of it is radiated from the overhead feeders. Is widespread in regard to range.	Includes the traction and compressor motors, the controller, and the collectors and overhead feeders.
(*h*) Mercury arcs	Is mainly of the directly-conducted (audio-frequency) type, but is accompanied by the radiated type. Is widespread in range in the case of sub-station plant.	Includes the types used at rectifier substations on d.c. supply systems, as well as the smaller types used for operating d.c. plant (such as lifts and cinema arcs) from a.c. mains.
(*j*) High-tension overhead transmission systems	Is of the radiated type. In addition to interference with broadcasting, interference with short-wave radio services has arisen from this source. Range is dependent upon the nature and extent of the discharge.	Such systems cause interference chiefly by corona discharge at insulators.
(*k*) Spark ignition-systems	Is of the directly-radiated type. Interference only with short and ultra-short waves.	Relates to types incorporated in motor-car and aeroplane engines.
(*m*) High-frequency medical apparatus	Is of the radiated type. The direct radiation is intense. The mains-borne radiation extends over a range of about 300 yards.	This class of apparatus normally operates much in the same way as a spark radio transmitter.

APPENDIX 3.

Technical Particulars of Various Suppression Devices.

Suppression devices			Type of interfering plant for which suitable	Remarks
Location	Circuit diagram	Description		
At source	Fig. 1	2 × 2 μF or 2 × 4 μF	Motors and generators of both d.c. and a.c. types	Condensers are mounted in metal case complete with terminals and fuses.
At source	Fig. 2	2 × 4 μF or 2 × 2 μF; 2 × 600 μH	Motors and generators of both d.c. and a.c. types	
At source	Fig. 3	2 × 2 μF; 1 × 4 μF; 1 × 600 μH	Rectifiers of the commutator type	Choke required when earthing of system is necessary.
At source	Fig. 4	2 μF or 4 μF	Contacts of flashing signs of various kinds, including road and railway control signals, electric bells, ovens, telephone switching plant, heating pads and other forms of thermostatically-controlled plant; also electric tramway and lift controllers	It is essential that the condenser should be inserted as near as possible to the contacts and on the mains side of them.
At source	Fig. 5	600 μH	Railway control signal (GreatWestern type)	The engine picks up a pulse when approaching signal box. Choke inserted in case, complete with insulating compound for outdoor fitting.
At source	Fig. 6	Choke 600 μH; condenser 0·1–2·0 μF; resistance 50–100 ohms	Flashing-sign contacts, electric tramways and lift controllers	Choke not always essential, but if fitted should be placed immediately preceding contacts.
At source	Fig. 2	2 × 2 μF or 2 × 4 μF; 2 × 600 μH	Vibrating - reed rectifiers	
At source	Fig. 7	Iron-core choke 50 H (at 50–100 mA)	Neon signs	If and where possible the cables from each end of sign to the transformer to be of the same length. Choke to be insulated for working voltage of 10 kV to earth, and preferably sectionally-wound.
At source	Fig. 2	2 × 4 μF; 2 × 600 μH to carry 50 amps.	Lift plant	Satisfactory suppression of interference from most types of lifts is secured by this means.

APPENDIX 3 (*continued*).

Suppression devices			Type of interfering plant for which suitable	Remarks
Location	Circuit diagram	Description		
At source	Fig. 8	2 × 600-μH choke coils	Tramway and trolley-bus systems	The device consists, in the case of trolley-buses, of two choke coils mounted in metal cases and inserted one in each line at the base of the trolley arm. A single coil is required in the case of tramways, supplemented at times by a condenser.
At source	Fig. 9	All condensers 2 μF	Mercury-arc rectifiers (high-frequency interference)	In the case of small rectifiers such as cinema equipments (low-voltage a.c. supply) this method has proved satisfactory.
At source	Fig. 10	Audio-frequency filter circuit	Mercury-arc rectifiers (low-frequency interference)	
At source	Fig. 11	Screened wiring and special suppressors at spark plug	Spark ignition system	Screening of the magneto will be necessary for complete suppression.
At source			High - frequency medical apparatus	Screening of the room in which apparatus is installed is necessary for complete suppression.
At source			Extra-high-tension transmission systems	The insulators should be of such a type as to limit corona and spark discharge to a minimum.
At listener's premises	Fig. 2	Mains filter: 2 × 4 μF or 2 × 2 μF; 2 × 600 μH	All plant which gives rise to mains-borne effects	Prevents high-frequency current from entering listener's premises via mains, but does not prevent radiation from neighbouring premises. This filter, in conjunction with screened lead-in at listener's set, will suppress locally-radiated interference.
At listener's premises	Fig. 1	2 × 2 μF	Mercury-arc (high-frequency interference)	Condensers supplied complete in case with fuses for insertion at incoming mains to listener's premises.
At radio receiver	Fig. 12	Additional smoothing to receiver if operated from d.c. mains; 2-H choke, 4-μF condenser	Mercury-arc (low-frequency interference)	Suppresses low-frequency interference. May either be incorporated in the receiver or made up as a separate unit.

APPENDIX 4.

Electrical Interference Questionnaire Issued by the British Post Office.

If interference is experienced when stations of the British Broadcasting Corporation are being received and it has been ascertained that the receiving set is in no way faulty this form should be completed and forwarded by post.

The interference will be investigated and particulars of the necessary suppression apparatus will be furnished without charge. The costs subsequently involved in the permanent installation of suppression apparatus cannot be borne by the Post Office.

1. Are you using a valve set or a crystal set? If valve, state number of H.F. and L.F.
2. Does your receiver draw any part of its H.T. or L.T. supply from the electric light mains?
3. Has your set or aerial, etc., been altered in any way prior to the commencement of the interference? (Please give particulars.)
4. (*a*) Are your neighbours simultaneously suffering the same interference as yourself?
   (*b*) Is the proportion of interference to music the same in neighbours' receivers as in your own?
   (*c*) To which British Broadcasting Station do you listen most frequently?
   (*d*) Is this Station affected by the interference?
   (*e*) Is the Daventry Long-Wave Station (5XX) affected?
5. Do you know, and can you give the address of, any local listener who hears the interference at a greater strength (in proportion to the broadcast transmission) than yourself?
6. (*a*) Does the interference cease when you disconnect (1) your aerial, (2) your earth, or (3) both? (Please ensure that your set is not oscillating when the aerial or earth is removed.)
   (*b*) Have you examined your aerial and earth wires and connections for frayed strands or bad joints?
7. State periods when interference is most pronounced.
8. If you are not a new listener, has the interference suddenly commenced?
9. Can you give date when interference first noticed?

APPENDIX 5.

Brief Description of Field-Strength Measuring Set.

The set consists of a double detection receiver having an intermediate frequency of 300 kilocycles per sec. and using anode modulation on the first detector. The band width of the intermediate-frequency amplifier is about 10 kilocycles. Both detectors contain microammeters in their anode circuits. The first detector is calibrated as a valve voltmeter. The output of the second detector is kept constant by means of an attenuator in front of the intermediate-frequency amplifier. The signal is normally received on a frame aerial, the first detector valve being connected across one half of the frame, while a balancing condenser is connected across the other half of the frame, the centre point of the frame being earthed. A powerful local-signal oscillator induces a measurable voltage in a small coil which can be connected either in series with the frame or directly between the grid and filament of the first detector. The ratio between the voltage measurements on the first detector under these conditions determines the step-up due to the frame. With the coil in series with the frame the attenuator is adjusted to give a convenient output on the second detector. The signal oscillator is then switched off, the signal to be measured is tuned in, and the attenuator is adjusted to give the same output as before. From these attenuator readings and the dimensions of the frame the field strength can be readily computed. A vertical aerial can be used in place of the frame aerial. In this case calibration of the vertical aerial is effected by measuring, with both frame and vertical, the signal from an oscillator placed a short distance away. The limitation of measuring sets having the attenuator between the oscillator and the receiver, due to the difficulty in eliminating direct throw-in from the oscillator to the receiver, does not arise in the set described; elaborate screening of the local signal oscillator is accordingly unnecessary.

The equivalent field strength of the disturbance from an item of electrical plant can very readily be measured by the apparatus described above, the radio noise field being treated in exactly the same manner as an ordinary carrier.

Discussion before the Wireless Section, 22nd November, 1933.

Mr. J. M. Donaldson: The electric supplier is concerned with this subject in two ways. In the first place he may be an originator of interference—purely, that is, as a producer. It must be borne in mind, however, that a supply business does not really end when energy has been generated and has been transmitted to the user's premises and a meter installed. The supply undertaker goes farther than that; he is interested in the general use as freely as possible of all current-consuming apparatus. He is therefore just as much concerned as the contractor, manufacturer, and supplier, in seeing that the apparatus which is supplied is as cheap, simple, and little liable to go wrong as is possible. Those of us who, in recent years, have had to change systems over from direct current to alternating current have had these points very strongly impressed on us by bitter experience. Nearly everybody whom the supply engineer has to change over has an expensive wireless set which he values highly, and if he loses its use only for an evening he complains! Again, we in the supply industry used sometimes to feel a little annoyed with people who had wireless apparatus, because they did not appear to use much current. As far as that is concerned, however, things have moved rapidly, and at the present time many sets take as much as 60 to 100 watts. Moreover, a wireless enthusiast keeps his set on for a long time, and therefore may be using a good deal more electricity for lighting

than he otherwise would. I should therefore like to say to the supply industry that, although wireless enthusiasts may be something of a nuisance at times, it looks as if they are going to be good consumers. There is not much guilt attached to the supply industry now in the matter of causing interference. The ordinary rotary convertor which is used is not an offender, but I know that the mercury convertor is bad. The supply engineer must take the larger view that he is out to give service of every electrical kind. We had a mercury rectifier in our district; it was a very old one, the second to be imported into this country. When it began life in a new sphere it caused a great deal of trouble to wireless sets. Eventually this was very much alleviated on an individual set by the Post Office engineers, who fitted a large number of coils, condensers, and so on; these certainly looked more like the product of the laboratory than of the workshop. Eventually correcting devices were installed at the substation. Broadly speaking, the electrical supplier should take the attitude that he does not want to produce trouble of this kind, though I do not think in the present state of the art it can be stopped altogether. The attitude which the supplier might be expected to adopt would be that of saying " These people are second-comers; let them effect their own cure." I have been told, however, that this cannot be done, although only the other day I saw the advertisement of a reputable firm guaranteeing entire freedom from all interferences. Some of the interfering devices of the bigger type can be dealt with very easily. I cannot think that any reasonable person would object to fixing even a fairly large condenser on a lift motor, because it can be stowed away quite easily, the cost cannot be great, and the interference of a lift motor may be serious. We were a little handicapped in the aural demonstration given by the author, because we could hear the noise of the machines themselves as well as the interference which they caused. That is where the value of the cathode-ray oscillograph lies—it shows what is really happening. I do not think that steps for curing interference should be carried too far. Operating a switch in the house gives a click, and no one would suggest that all switches should be paralleled with condensers to avoid it. Further, it is not usual to have the vacuum cleaner running when one is enjoying the wireless; it would not be done because of the noise of the apparatus itself. The same argument applies to some of the other apparatus, such as the sewing machine. It is difficult to see how one can fix a condenser of any reasonable size as a self-contained apparatus on these smaller appliances of which complaint is made. I gather that the ordinary induction motor of commerce is not a great offender. I should like to ask what would be the effect of the commercial condenser which is very often used in parallel with a large induction motor in order to raise the power factor. This is quite a common arrangement, and I would inquire whether the condenser is placed in such a way as to be effective.

Mr. J. S. Forrest: I notice that the value of + 40 decibels is suggested for the signal/noise ratio. I should like to know whether this is to be regarded as an ideal to be aimed at, or as a value which could be obtained under all practical conditions. Consideration of this value in conjunction with the minimum signal strengths in Table 1 shows that for wavelengths below 20 metres any disturbing signal which has a field strength greater than $0{\cdot}1\,\mu$V per metre will give rise to "interference." For the wave band 20 to 200 metres, a disturbance having a signal strength greater than $0{\cdot}2\,\mu$V per metre will give rise to "interference." Similarly, for the broadcast band of 200 to 2 000 metres, "interference" will be produced by any signal having a field strength greater than $10\,\mu$V per metre. I suggest that these values for interfering field strengths are much too low, and that the proposed French value, $166\,\mu$V per metre, is more reasonable and more likely to be attained in practice. Table 2, which gives the interference level from a 132-kV power line, confirms this opinion. On the basis of the signal/noise ratio of + 40 decibels, and the minimum signal strengths given in Table 1, it would appear that this line is giving rise to severe interference on all wavelengths and under all conditions. This conclusion is not supported by practical experience on the Continent, in America, or in this country, and it is generally recognized that a transmission line insulated with the suspension type of insulators does not give rise to severe interference. In fact it may be mentioned that it is possible to obtain good reception of Continental broadcasting in daylight conditions by means of a wireless set located inside a 132-kV substation. It is stated underneath Table 2 that the noise level is rather difficult to measure, and I suggest that the values in Table 2 perhaps include noise due to sources other than the 132-kV transmission line. In Appendix 3 it is remarked that the insulators should be of such a type as to limit corona and spark discharge to a minimum. I think it should be mentioned that radio interference is not the primary consideration in the design of a high-tension transmission system, and that it is undesirable to increase the corona limit too much; in fact, it is not uncommon practice artificially to decrease it, in order that steep-fronted travelling waves may be attenuated rapidly. The wireless relay systems which are becoming so popular are a very interesting way of evading the trouble due to radiated interference, because they permit a large number of subscribers to be fed from a receiving station remote from any interference. With regard to the incidence of the cost of suppressing interference, I suggest that the necessary funds might be obtained, at any rate in part, from the licence revenue. Finally, I should like to ask the author what percentage of complaints has been traced to faults in the complainants' own wireless sets. I believe that in other countries it has been found that this percentage is quite high.

Prof. C. L. Fortescue: The gist of the subject lies in the author's last remark: it is no longer an electrical or a technical problem, but entirely a psycho-economical problem; it is a question of how much the owner of the broadcast receiver is prepared to pay for the privilege of picking up weaker signals. The cause of the trouble is the property of the arc which always forms at a break of circuit; collapsing suddenly, it sets up a surge which radiates over a wide spectrum, and every receiver which is exposed to this radiation is bound to absorb a certain amount of it. Unless we can suppress the source, the

surge, we shall have to tolerate the interference. Since there exists an organization, under the control of the G.P.O. and the B.B.C., for looking into the question of these complaints, some powers should be given to it to investigate all the complaints that are sent in. Those who send in complaints should be called on to pay a deposit, which could be returned if the complaint appeared to be justified. This would assist in finding out how much the owner of the receiver is prepared to pay for the privilege of receiving distant programmes. If on investigation it is found that owing to the interference signals of a reasonable field strength cannot be received, then this organization should be given powers to compel the owner of the interfering machine to put it into a non-interfering condition. I do not think we shall be able to eliminate the interference caused by electro-medical apparatus, except at great cost.

Mr. H. Bishop: I should like, in the first place, to raise a question concerning the title given to this discussion. It refers to the reception of radio broadcasting, but I imagine the G.P.O. and the Services are also interested in this question of interference, especially so far as the reception of short waves is concerned. There are 6 million receiving licences at the moment, and the number is still rising. This means that about 50 per cent of the homes in this country are equipped with wireless sets. The interference trouble became evident about 8 years ago, and the B.B.C., in conjunction with the Post Office, took steps to investigate it. The work was difficult, because there were, and still are, no statutory powers, and persuasion alone could be employed; furthermore, at that time the transmitters of the B.B.C. were of low power, and in many parts of the country the field strength from the nearest broadcasting station was undoubtedly low. In the last few years, however, bigger stations have been built and the average level of field strength is now considerably higher. On the other hand, receivers have become more sensitive, but the sensitivity to which a receiver is normally adjusted is very much below its maximum, at least for ordinary home listening. There have been numbers of frivolous complaints, and Prof. Fortescue has suggested that the complainant should pay a small deposit when he makes the complaint. This system is actually in operation in Denmark at the present time. The B.B.C. prepared a questionnaire, which I am glad to see the Post Office have adopted. This procedure has reduced the number of frivolous complaints considerably. The author stresses the importance of the various wave-bands and the minimum field strengths to be protected. These values are of extreme importance and merit further study. Another factor which is of considerable importance is the average depth of modulation of B.B.C. transmitters. It is generally agreed that it is impracticable to cure interference by arrangements at the receiving end, and it is therefore essential that the trouble should be cured at its source. The problem of additional cost naturally arises. The fraction of the total cost is difficult to determine, because, for example, the cost of the condenser to be connected across the contacts of a switch may be a large fraction of the cost of the switch itself, but quite a small fraction of that of the whole piece of apparatus of which the switch forms part. To protect against unfair competition, it is essential that if a suppression device be included all manufacturers should fit it. That naturally implies some sort of persuasive or legislative powers. Large numbers of listeners do not realize that they are suffering from interference, and we have evidence that the trouble is antagonizing listeners against the greater use of electricity and the development of the domestic load. In amplification of what Mr. Donaldson has said, I notice the statement in the current issue of one of the technical journals that if half the sets in the country were mains-operated, and averaged 40 watts each for 500 hours a year, the total consumption would be about 60 million kWh, equivalent to the amount sold for all purposes in a town the size of Stockport. In countries abroad there is a good deal of legislation on this subject. In Denmark, Rumania, Belgium, and Spain, there are specific laws against interference, and in other countries —notably Italy, Hungary, Sweden, Holland, and Yugoslavia—legal action against interference has been taken. Great Britain is one of the few countries in which this problem has not so far been tackled. The balance of legal principle and precedent, however, would seem to afford relief to a man whose reception is interfered with by the escape of parasitic electrical energy from electrical apparatus in the hands of his neighbour. The B.B.C., and to some extent the set makers, are blamed for interference, and it is rather difficult to convince the non-technical listener that they are not in fact to blame. The greater publicity which has recently been given to this matter, due to the Institution's Committee on Electrical Interference with Broadcasting, has led to many more complaints, which proves the contention that there are many people suffering from this trouble who do not know what steps to take to cure it. The Post Office are doing admirable work in tackling the problem, but they are overwhelmed. It is obvious that the trouble must be cured at its source, and I think that much can be done by friendly co-operation between all the parties concerned.

Mr. R. T. B. Wynn: There has been a little criticism of the suggestion that interference might be suppressed down to a level of 40 decibels (a voltage ratio of 100 : 1). Suppressors have gradually improved in their efficiency since the early days, and a far greater degree of suppression is obtainable to-day than was available in the past. Whenever a serious attempt is made to tackle this type of work the problem of what is meant by suppression arises, and there is difficulty in defining the the efficiency of a suppressor. If, for instance, signal strength and the wave bands to be protected are disregarded, it is considered that 30 decibels suppression behind most types of programmes is not sufficiently satisfactory, particularly when the interference is continuous. Consequently 40 decibels is suggested. It is of interest to note, however, that the 40-decibel condition demonstrated on the gramophone record gives a background of interference more or less equivalent in level to needle-scratch; and many people are prepared to criticize gramophone transmission on this account. Again, suppression to the extent of 40 decibels behind a symphony concert is not considered by musicians to be good enough in soft passages. The B.B.C. rents from

the Post Office music lines on which the noise level is more than 50 decibels below the level of the programme, and it is submitted that this is the sort of standard which should be aimed at in this work. Having obtained an idea of the signal/noise ratio which is satisfactory—and it is very much a matter of opinion—the next question which must be considered is the signal level to be protected. The minimum signal chosen, namely 1 mV per metre, for wavelengths over 200 metres, is one at which a modern receiver will, in the absence of interference and with automatic volume control, give an enjoyable programme. The matter has to be considered in terms of wavelengths because the levels of signal strength available are by no means as high as 1 mV per metre in the reception of short-wave services, or in the case of the ultra-short waves contemplated for television. These figures are open to criticism, but the intention has been to attempt a high standard, perhaps beyond that which can be obtained at the moment, particularly in the case of short and ultra-short waves, and to depart from this standard only when it is necessary to do so. Any measurable standard which is adopted will apply in both directions, because it will permit the manufacturer of a piece of electrical equipment to have some test applied to it which will enable him to prove, if anyone complains about his apparatus, that he at least is not guilty. Further, if the standard is too low it will regularize interference which, though it may be an improvement on the present state of affairs, will not be good enough for the future.

Col. A. S. Angwin: The art of wireless is restricted by as many regulations as any other art which is being exploited at the present time. Both international and national regulations are in force for the use of the appropriate frequencies and for the regulation of interference between wireless services. It is perhaps somewhat of an anomaly, therefore, that in this country there is no regulation whatever of a national character for safeguarding interference to wireless reception arising from other services. One of the critical questions to be decided is, can the desired regulation be obtained by means other than some form of legislation, to which apparently most of the other countries of Europe have been driven? While we are attempting to regulate interference it is important to bear in mind the development which is taking place on the shorter wavelengths; they are being used more and more for commercial purposes, and it must not be forgotten that the development of television is only possible on the short wavelengths. Comment has been made on the more stringent conditions to be applied, as regards the field strengths which can be tolerated, in the case of these shorter wavelengths. Whilst this condition is essential, it is, however, fortunate that the interference on these frequencies is not usually of such a high order as on the lower frequencies, and the propagation is more rapidly attenuated. It is equally important to consider this range of frequencies, and I am quite sure that, had it been possible to demonstrate here a television experiment, the mutilation on television caused by unprotected apparatus would have shown up even more than the audible interference effect on the broadcasting wavelength.

Mr. A. J. Haswell: Commercial motors, which include those for lift machinery, although possibly efficient for their duty, are the chief disturbing factors in radio interference, commutation being the chief difficulty, especially on d.c. circuits. We have frequently found such a motor to contain brushes of various grades, and there is in the brush situation great opportunity of helping the suppression of interference. We are rather too much inclined at present to fix condensers or other suppressor apparatus across a troublesome motor, without first ascertaining whether the noise can be cured by adjustments or a slight alteration in design which can easily be arranged with the manufacturers. A large number of experiments have been made with various grades of brushes, and the variations observed are wide. I should like to mention one interesting point which may in future engage our attention in connection with radio interference, namely, that in accepting the fact of audio-frequency sympathy between a motor (or dynamo) and a radio receiver there has recently arisen the interesting possibility of the frequency of the mechanical noise of the machine being that of a harmonic of the supply frequency. Instances of this have been observed, and within the last few days experiments have been carried out on a pump motor where, in addition to the motor noise, the pump pulse and working noise were also faithfully reproduced.

Mr. L. B. Turner: We have had some excellent demonstrations of that class of interference in which it is technically possible for the injured person to protect himself; but we must not forget the other class, where the antenna is located in the disturbing field. If this field is not suppressed at the source, for technical reasons no escape is possible short of removing the antenna to another part of the country. In the problem of electrical interference with broadcasting, a mere accidental by-product of one kind of appliance is destructive of the essential action of another kind of appliance: surely a condition not tolerable in a civilized society. Some form of compulsory control is necessary, and this makes the ability to measure the amount of the interference very important. The author and many other speakers have referred to the noise level; the noise is said to be so many decibels above or below a signal of 1 μV per metre. Now the decibel notation serves to compare powers without reference to their qualities, but it is as otiose to say that the noise is so many decibels above the signal, without specifying the nature of the noise and of the signal, as it is to say that a certain yellow light is so much brighter than a certain red light; their relative values depend on the way the light is being used, on the nature of the eye that sees it or of the plate or photo-cell that is being influenced by it. This contention was illustrated by the gramophone record which the author played. We had a speaker with a " boomy " voice, and the interference which was superimposed was of a high-pitched character; I see no significance in the statement that the one was 20 decibels above or below the other. Are the r.m.s. values being compared? Or is it the squares of the peak values, or some other function, of the two trains of sound? It is very important for any advance in dealing with interference that we should both be able to measure and

know what we want to measure. We want available better police work, as it were, in this matter, than we have in the suppression of noisy motor-cycles. The noise of the motor-cycle is illegal, but because it cannot be, or is not, suitably measured the regulations are not enforced. Turning now to the origin of the interference: we know that it emanates from a circuit undergoing a sudden change of current, a discontinuity. Commonly this is caused by some form of make or break of circuit (generally between metal contacts), and sometimes owing to the curious behaviour of a gaseous conductor. I think in practice the break matters more than the make, and I have made a brief calculation to illustrate this. As an example of a system which can be set into oscillation and so interfere with wireless receivers, I take a piece of 100 lb. air-line loop $\frac{1}{10}$ mile long. This will have an inductance of some 400 μH and a capacitance of some 800 $\mu\mu$F, and may be represented approximately by the circuit of Fig. A. If a current of 10 amperes flowing between A and B is suddenly interrupted, an oscillation arises of frequency about half a million cycles per sec. and with initial peak rate of change of current of about 36 million amperes per sec. It is this value

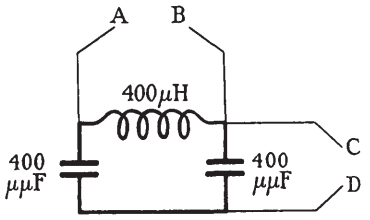

FIG. A.

which determines the strength of the disturbance radiated from the system. Now consider what potential difference suddenly applied across CD would produce an equal rate of change of current. It is readily calculated as about 14 kV. This suggests that breaks rather than makes are likely to be the more troublesome. As to the spark which may occur at a break, this serves to make the break less sudden. I think the spark should be regarded as an alleviating symptom rather than as a cause of the trouble. Whether a break drawn out by a spark ever causes more disturbance than an ideally sudden break is an interesting subject for investigation.

Mr. C. C. Paterson: Mr. Wynn pointed out that Great Britain was the only large country which up to the present had not introduced some regulations; this may be rather a matter for pride than shame, because one can rush into regulations too soon. There are many now who speak of enacting legislation, but it is quite clear from this discussion that, even if we had the opportunity, none of us would know exactly what to lay down in the way of regulations to secure a practical cure for the trouble. It is very easy to say that every interfering person will be held responsible for the interference he causes, but that would not be satisfactory; there must be a practical way to surmount the difficulty. The wireless enthusiast is sometimes said to be trying to clear everyone else off the road just because he wants to make his apparatus work satisfactorily. I think that many who allege this forget that the rest are not using the road for any legitimate purpose; in effect, but in all innocence, they are throwing obstructions in the way of the legitimate users of the road. The wireless enthusiast is often called a late-comer, and it is said that therefore he must get on as best he can; but he is not a late-comer in the highway that others are using; he has a highway of his own, and it is the only one he can use, so that he ought to be considered in the matter. More important than this, however, are the big industrial and public issues which will depend more and more upon a " clean " ether for radio purposes. A very great deal will depend on the attitude of the manufacturers, on whom it will rest to try in a practical way to apply these devices to their apparatus, and to do so cheaply. Is it impossible that all new apparatus sold and installed in this country should have suppression devices incorporated? This, coupled with the steady obsolescence of existing apparatus, might then gradually bring about a cure of the worst of the trouble.

Mr. W. F. Floyd: The remarks of a number of speakers in the discussion have implied that interference is caused mainly through an irregularity in the operation of a machine. It must be understood, however, that interference may be caused by the normal operation of machinery, as is indicated by what Mr. L. B. Turner has said. If a manufacturer proposes to put a machine on to the market which is to be unimpeachable from the radio-interference standpoint, he must incorporate in it a disturbance-suppressor unit, no matter how well designed his machine may be. This, however, by no means disposes of the problem. Under certain conditions, a particular disturbance-suppressor unit may resonate with the circuit to which the machine is connected, the resulting interference being more serious, possibly, than if no unit at all were employed. Further, the particular type of suppressor-circuit arrangement which is found suitable for one machine in a certain situation is unlikely to be effective universally. Even should a particular suppressor-circuit arrangement be found effective universally, an economic consideration arises, for the particular suppressor device in this case would clearly be that which produced the maximum attenuation of the interference generated by the machine, and hence it would be likely to be the most expensive as far as initial cost is concerned. It is economically unsound that every user of a machine should have to pay for equipment which is only required in, say, 2 installations out of every 10. The whole problem should be approached, therefore, *in situ*, and not in the factory where the machine is made. With regard to the matter of the relative levels of the desired signal and the interference, it seems to me that before any quantitative data can be put forward as a basis for legislation, some research work will have to be carried out on the extent of the " masking " of one sound by another of different intensity, pitch, and wave-form factor. I do not understand at present what is meant by the difference in level of the two signals in this context. Both the subjective aspect of the problem and the purely objective matter of the definition of terms have to be investigated and explained.

Mr. H. C. Turner: I notice that the author does not refer to the capacitor motor, which is on the market in America and contains a suppression device in its

own frame. The manufacturers claim that this motor satisfactorily prevents interference with wireless reception in the neighbourhood, and I think it is well worth while for these claims to be investigated. I should like to ask whether the Post Office have any statistics of the incidence of interference. After all the investigations made, the Post Office could surely give a map showing the " black " spots for each area. I think we can disregard those cases where the culprit is also the victim; so that vacuum cleaners and hair dryers, except when two or three are gathered together, as in a barber's shop, can be ignored. So far as the motors of lifts, neon lights, and electro-medical devices are concerned, the householder is very much in the hands of the owner of the block of flats, or of his neighbours.

Mr. C. E. G. Bailey: The question of the modulation percentage used in definitions of signal strength has been mentioned but not actually discussed. Presumably the figures quoted by the author for the signal/noise ratio in connection with the gramophone record were given for field intensities when the sounds were equalized. On the other hand, in comparing the ratio of a broadcast signal and an interfering signal the field intensities of the waves radiated are compared. The interfering signal has no carrier wave and, roughly speaking, corresponds to a carrier wave modulated 100 per cent. If, therefore, one compares this sound with that which is produced in a broadcast receiver by a carrier wave modulated approximately 30 per cent, one must add 6 decibels to the ratio between the signal and the noise in order to obtain the same comparative results. For example, if a broadcast transmitter is modulated 30 per cent and one wishes to obtain a signal/noise ratio of 20 decibels, then the noise must be attenuated to 26 (and not to 20) decibels below 1 μV per metre. This argument applies to an even greater extent in concert transmissions, in which, in order to maintain an effective crescendo, the average modulation percentage may be lower than 30 per cent.

Dr. L. E. C. Hughes: The noise in radio sets due to an external noise-field adopts the carrier of the required transmission, and therefore the comparison should be made between the integration of the noise-field as compared with the integration of the side-frequencies of the required transmission over a specified frequency band. If this comparison is to be made with a field-strength measuring set, it is necessary to tune out the carrier with an acceptor shunt of very low decrement. I have had considerable experience of measuring speech/noise ratios by a method originally proposed by A. H. Reeves* for high-grade microphones, but which is easily adaptable to other high-quality circuits such as are used in broadcasting. In principle, the speech output of the transmission is attenuated, by a standard attenuator, until the speech just vanishes into the noise. In practice it is not possible to attenuate speech apart from noise in a single channel, and therefore the speech from a source of similar quality is attenuated and mixed with the output. Two microphones are placed side by side in a damped room, with their outputs correctly mixed and with their series attenuation adjusted so that, on repeated switching, their speech outputs appear to be of equal level. The microphone under test is then placed in a sound-proof box or in another room, and the speech output of the comparison microphone is adjusted by series attenuation until a consistent comparison is obtained with the noise output from the test microphone. The increase in attentuation of the comparison microphone is then taken as the speech/noise ratio. With practice, agreement within about 2 decibels is possible, because the point at which some words, and not the sense, in a conversation can be detected through typical noises is fairly critical. The chief difficulty is in deciding upon the listening device, since an indicating device is not permissible on acoustic grounds. I have heard elsewhere the record which has been demonstrated here by the author, and have received totally different impressions of the speech/noise ratios recorded on it, owing to the difference in the reproducing response curves. For the highest-quality performance, such as it is hoped to obtain in broadcast reception, it would appear necessary to use moving-coil head-receivers on which to detect the balance of speech and noise. These were used in the method described above. For the routine measurements of speech/noise ratios in domestic receiving sets on location, it is necessary to use a portable outfit which generates normal announcers' speech of high quality and attenuates this in known steps until an aural balance is obtained with the noise normally developed by the receiving set, when adjusted to normal gain. This also applies to external noise-fields, the test being performed with an unmodulated carrier.

Mr. J. M. Kennedy: From the paper, and more especially from the experiments shown, it would seem to be impossible to have an all-electric house and yet to receive broadcasting. I have in my house examples of nearly all the apparatus shown by the author, and I experience perfectly good reception. What is the reason? How did the author obtain the results he has demonstrated, which to my mind exaggerate altogether the difficulties? I think it is incorrect to say that scientific development has reached such a stage that it is impossible to improve radio apparatus. Surely radio receivers can and will be improved to such an extent that these small domestic appliances will not cause any interference. I am surprised that the author did not include in his experiments the interference obtained from an ordinary Post Office telephone receiver. I can show him examples where such interference is the most serious disturbance in an all-electric house. It would be interesting to know whether the Post Office are installing condensers on all their telephones and extension switches.

Mr. H. B. Swift: With reference to the questionnaire issued by the Post Office, I consider that the most important question is omitted. It is: " Give the date when the set was purchased." There are many sets in use to-day which have been in existence for 6 or 7 years, and in which selectivity is almost absent, and it is in connection with these sets that complaints generally arise. The answers to the question I have mentioned would no doubt settle many disputes and probably lead their owners to obtain more up-to-date receivers, which would not be so prone to pick up interference. With

* *Electrical Communication*, 1929, vol. 7, p. 253.

regard to the interference caused by trolley-buses, I think that much of the trouble here is due to the fact that the vehicle is entirely insulated by the rubber tyres. In view of the fact that metal bodies are rapidly becoming the standard, and that if a leak occurs on a trolley-bus fitted with a metal body serious trouble may arise, something ought to be done in the way of earthing the vehicle. I suggest that it would be possible to fit a steel thread to the tyres, which could be connected to the body of the vehicle. This would not only have the effect of preventing boarding passengers from getting shocks, but would also, in conjunction with the insertion of suitably-connected condensers, considerably help in preventing radio interference.

Mr. E. W. Braendle (*communicated*): The author does not refer to the interference caused by small generators employed as accessories to the receiving apparatus. The methods necessary for the elimination of interference derived from a small motor-generator set used as a source of power supply for a wireless set are far from having the degree of simplicity indicated by the author, particularly when a high-gain receiver is operated on short wavelengths. This type of plant radiates at one or more (usually more) definite frequencies, the value and multiplicity of which appear to have little reference to the type of generating plant employed. For some time past it has been common practice to fit special chokes, condensers, or a combination of both, to the generator, to overcome its own individual form of radiated interference. In certain cases complicated filters are necessary, upon the design of which considerable time and expense has been expended. I should like to ask whether the author can give any information on the following points: (1) The relative intensities of radiated interference over the spectrum of frequencies above 3 000 kilocycles per sec. (including harmonics of lower frequencies), with particular reference to the ultra-high frequencies, for any given type of apparatus. (2) The extent to which both frequency and intensity are affected by the design of the apparatus. (3) The manner in which the initial design could be modified so as to reduce the need for the subsequent application of filters. (4) The extent to which the intensity/frequency curve varies for motors and other apparatus of identical type.

Mr. L. Friedman (*communicated*): I shall confine my remarks to two kinds of interference. The first is that from automobiles and aircraft, i.e. from the coil- and magneto-ignition systems of petrol engines. It happens that the only prospects for a television service appear to be on the ultra-short-wave band, and therefore the abolition of interference on this wave band is of the greatest importance to the further development of television. The difficulties encountered in radiating on ultra-short waves with a comparatively high power, and the strong attenuation of the very high frequencies involved, considerably decrease the signal/noise ratio. In addition to that given by the usual screened wiring and the fitting of special suppressors (resistances) at the sparking plugs, considerable freedom from interference can be obtained by careful design. In some cases, where the design is such as to minimize the interference, it is not even necessary to take other precautionary measures. Experiments have shown that interference on ultra-short waves varies considerably with different makes of cars. With the new Ford car very little interference seems to be produced. This is no doubt due to the unusual position of the distributor, making the connecting links from the distributor to the sparking plugs very short. In any case, practically no interference has been observed on an ultra-short wave set operating at a few yards from the running engine of this type of car. On the other hand, some very bad interference has been experienced with other well-known makes. Interference on ultra-short waves from motor-cars can be minimized inexpensively, and to such an extent as to make it negligible. There are two factors which will, in time, decrease this type of interference; one is the increasing use of car radio sets, and the other the use of crude oil for motor-cars. Nevertheless, legislation to stop interference will be necessary sooner or later, as ultra-short waves may be very useful in other special circumstances, besides their use in television. With regard to my second point, I should like to know why condenser suppressors are not fitted by the G.P.O. on automatic telephones. The dialling produces interference noises, which, in certain instances, are reported to be very serious. Interference of this sort is noticeable on all but the local B.B.C. transmitters.

Mr. F. T. Lett (*communicated*): The author expounds the ideal condition in which the interference is suppressed at the source. This condition is not likely to be met with in practice for some time, but unless something is done immediately the sale of large receivers will be ruined, as approximately 85 per cent of these are sold to customers in town areas. Much can, however, be done by the radio manufacturers themselves in designing better receivers. The receiver and the lead-in system should be so screened that only electric waves induced in the horizontal part of the aerial are received. This means screened aerial leads, an efficient mains filter, and careful screening of all coils and wiring in the receiver itself. In very few instances has it been found that a static level of more than 15 μV per metre (wavelength 200–2 000 metres) exists at a height of 20 ft. above a building. A well-screened set, when used in areas of high noise level, will not reproduce any noise from the loud-speaker if the aerial is removed. When a receiver with a sensitivity of 1 μV is used in an area where a static level of, say, 100 μV per metre exists, the effective band width of the receiver largely determines the signal/noise ratio. A sharp low-frequency cut-off which is variable, either automatically or manually, gives effective reduction of noise, usually without loss of intelligibility (as in normal telephone practice).

Mr. H. S. Pocock (*communicated*): The author refers to the Committee appointed by the Institution to study the question of interference and to report to the Council. Naturally, the proceedings of this Committee are confidential at this stage, but a report* on the progress made was recently issued with the authority of the Institution. It was stated in this report that the Committtee "reviewed various possibilities of bringing suppression devices into use without having recourse to legislation." Does this mean that there is any general

* *Journal I.E.E.*, 1933, vol. 73, p. 543.

feeling that legislation should be avoided? If some general agreement can be reached in the electrical industry on the subject of suppressing interference, then it would seem to me that that moment should be seized upon to introduce legislation to ensure that agreement continues. There can surely be no objection to the legal enforcement of a policy on which those affected are already voluntarily agreed. In the absence of legislation there will always remain the probability that whilst some manufacturers will co-operate and fit suppressors to their apparatus, others in competition with them may decline to do so. Such a state of affairs will obviously be unfair. Legislation could take into account that a period of time should be allowed before the law became operative and that, in the case of existing installations, evidence of interference would have to be produced before action could be taken. There must be very many instances where plant does radiate but without causing interference with wireless reception. The question of who shall bear the cost of making apparatus interference-free is, I believe, the chief obstacle at present. Cannot this be met on the broad basis of the benefit to the industry as a whole which must result from increasing the popularity of electricity in the home? Again, if legislation were introduced it would seem that it could be turned to good account by the British manufacturer, since foreign apparatus could no longer be imported until it was made interference-free. The benefit of this hold-up, if only temporary, should go some way towards offsetting the cost, in certain branches of the industry, of fitting suppressor devices to new equipment of British manufacture.

Mr. M. G. Scroggie (*communicated*): It seems to me that the point raised by Mr. L. B. Turner is of great importance. Sounds of different frequencies cannot be compared unless account is taken of the variation of sensitivity of the ear with frequency. Thus the difference in threshold intensity between a note of 100 cycles per sec. and one of 2 000 cycles per sec. is about 40 decibels, which is not a negligible factor in the matter. If in the sound-measuring apparatus a network is included to attenuate the frequencies to which the ear is less responsive, it holds good only at one level of intensity: for louder sounds the difference is much less than 40 decibels. It would appear, therefore, that very careful consideration is necessary in defining the tolerable signal/noise ratio, for it depends on the frequencies of both sounds. In fact, the figures given in the paper are quite meaningless.

Mr. A. Morris (*in reply*): The discussion has mainly centred around the two chief aspects of the question, namely the technical and what may be described as the political. In regard to the latter aspect, the question is that of the regulation of electrical interference either by legislative measures or by voluntary means other than legislation. Mr. Donaldson and Mr. Paterson have spoken fully on this matter in very sympathetic, and what will doubtless be regarded by all interests as extremely conciliatory, terms. Prof. Fortescue and Col. Angwin have also contributed by clearly posing the essentials of the question. Mr. Pocock raises issues with the Committee appointed by the Institution, which issues will doubtless be fully considered. The final answer to this question is not within my province. It is a vital question and will doubtless be settled by the interested parties when it has been fully explored. I shall content myself by pointing out the advantages of voluntary regulation in the first instance, backed by legislation at a later date and at a time when the electrical industry requires legal means for regularizing and protecting its interests.

If the whole question of electrical interference is not to be shelved, definite technical requirements must be laid down, no matter what the nature of the political settlement may be. It is these technical considerations with which I am concerned and it was the main object of the paper to suggest a simple practical, technical basis upon which the question may be dealt with.

For the sake of simplicity of statement and of ease and smoothness of operation, in the case of any regulation which may ultimately be framed, it is desirable that the large number of variants with which this question is concerned should not be permitted to complicate the issue unnecessarily. If this can be safely accomplished, and in my view it can, then there is actually only one fundamental quantity which it is necessary to define, measure, and limit in magnitude, namely the maximum permissible value at the receiving site of the radio noise field due to an item of electrical plant. Clearly it is this quantity which the manufacturer of electrical plant urgently requires to be advised of, if he is to make any progress towards a settlement of the question. An expression for the computation of this quantity, in terms of certain other quantities, is furnished later in this reply. These latter, the magnitudes of which have already been quoted and which appear in the paper, constitute the basis for arriving at this fundamental quantity and consist essentially of a satisfactory value for the signal/noise ratio at the output of the receiver, the minimum value of broadcast field strength to be protected (to the ultimate degree envisaged by the aural signal/noise ratio), and suitable average limits to the figure representing the degree of modulation of the broadcast transmission.

Various criticisms of the figures quoted in the paper have been made, notably by Dr. Hughes and Messrs. Forrest, L. B. Turner, Floyd, and Scroggie. In the main, the criticisms have not been of a constructive character and as a consequence it may be correctly inferred that a completely satisfactory and rigidly scientific solution of this question is not at present available.

The criticisms can perhaps best be dealt with by amplifying the statements made in the paper. It will be well to say at the outset that the proposals are based upon the principles employed in the present-day engineering technique of radio communication circuits, and that the application of this practice to the question in hand will permit of considerable progress being made towards a technical settlement of the question.

It may be assumed that the interference set up by an item of electrical plant consists of an infinite series of uniform steady-state voltages at radio frequency, distributed in a continuous spectrum. When these components are combined with the signal carrier and are passed through the detector of a radio receiver, an

infinite series of beat-notes will result. Of these beat notes, those which are within the audible range and within the acceptance band of the audio-frequency amplifier of the receiver will appear as noise at its output terminals. The mean-square value of the interfering radio-frequency voltages can be measured in terms of an equivalent radio noise field-strength, by means of a receiver suitable for the measurement of carrier fields; for example, the receiver described by Messrs. Friis and Bruce in the *Proceedings of the Institute of Radio Engineers*, 1926, vol. 14, p. 507, in a paper entitled "A Radio Field-strength Measuring System for Frequencies up to 40 Megacycles." A description of the set used for the measurements recorded in Table 2 has been added to the paper as Appendix 5.

Under practical interference conditions the receiving aerial is influenced in general by the carrier field, S decibels relative to 1 μV per metre, modulated by a signal to a degree of m decibels, as well as by an equivalent radio noise field, N decibels relative to 1 μV per metre. The resulting audio-frequency output is a mixture of signal at one particular average level and of noise at another average level. It is the ratio of these two levels which is referred to in the paper as the audio signal/noise ratio, X decibels of the transmission. In the gramophonic demonstration, the various quoted values of signal/noise ratio also referred to this quantity.

The magnitude of the signal/noise ratio in any particular broadcast transmission may be obtained from volume-indicator measurements of the level of the signal in the absence of the noise field, and of the level of the noise in the presence of the unmodulated signal carrier.

In any particular case the level of the noise in the presence of the unmodulated signal carrier will be n decibels greater than the level of the noise in the absence of such carrier. Calculation from a noise-level measurement made under the latter condition would result in a value n decibels greater than the true signal/noise ratio of the transmission.

The actual interfering effect of the noise will depend upon the value of the signal/noise ratio; the greater the interfering effect, the smaller the ratio. It will also depend, however, upon the character of the noise, i.e. whether the noise consists of complex sounds or of single-frequency tones. The continuous, periodic, or intermittent nature of the noise, as well as the actual power-level at which reception takes place, e.g. whether at headphone or at loud-speaker strength, will also govern the result. These latter features have been properly raised in criticism of the suggestion to utilize signal/noise ratio only as the criterion of reception. The criticisms are not, however, as serious as they would appear, since the figure of 40 decibels, recommended in the paper as the desirable objective for the value of signal/noise ratio in the reproduction of high-quality broadcast matter, does in fact take into account all these features. It applies only to continuous or steady interference of the type which gives rise to complex sounds of a character common to the interference from electrical plant, and relates to a power-level which is adequate for satisfactory loud-speaker reception. The gramophonic demonstration presented in this connection was governed by these features. It gave a reasonably accurate aural indication of the effects of noise, present in various degrees, upon a programme, although it is conceded that the unavoidable presence of needle scratch slightly marred the demonstration of the 40-decibel signal/noise condition. The demonstration undoubtedly emphasized the widely divergent opinions on the question of what constitutes a tolerable amount of noise, although there appears to be general agreement that a signal/noise ratio of 40 decibels represents essentially interference-free conditions.

The permissible strength of the radio noise field at the receiver can be deduced from the strength of the signal carrier field and the signal/noise ratio, etc., by the following expression, the various symbols in which have been previously defined:—

$$N = (S - m) - X$$

No misconception appears to have been caused in regard either to the measurement or the actual magnitude of the minimum value of broadcast field strength to be protected. Objection to certain of the figures has, however, been raised on the ground that so far as the short-wave and ultra-short-wave bands are concerned, too weak a field would thereby be protected. The figures of 20 μV per metre and 10 μV per metre respectively, are based upon the average fields with which the services in such bands are commonly called upon to operate. The objection to them is hardly valid, since it appears to arise from apprehension as to the practicability of protecting them to the recommended degree. In regard to the figure of 1 mV per metre for medium-wave and long-wave transmissions, it should be pointed out that individual receivers will in general be thereby protected only in respect of their respective national broadcast service transmissions.

As a matter of interest I include a Table (see page 261) giving representative signal and noise field values, appropriate to the operation of long-distance radio communication services, for which much smaller values of signal/noise ratio than are required for broadcasting can be tolerated.

A signal/noise ratio of 5 decibels will permit of satisfactory aural reception on commercial telegraphic services, which can often be operated with signal fields as low as 1 μV per metre.

I propose now to reply in detail to the remarks of various speakers. I agree with Mr. Donaldson that steps for the suppression of interference should not be carried too far. There is, of course, no need to deal with occasional interference of the type produced by the operation of some types of switch. It is true that the ordinary type of induction motor gives little trouble. The question of the use with such machines of parallel condensers for starting and power-factor-correction purposes has also been raised by Mr. H. C. Turner under the title of the "capacitor" motor. Machines so equipped produce little interference, but the freedom is inherent in the type and the condenser functions from the anti-interference point of view only during switching operations at starting.

In reply to Mr. Forrest, the value of 40 decibels for signal/noise ratio is a recommended standard to be aimed at. Taken in conjunction with the recommended values

of minimum field strength to be protected, it is thought that it should be capable of practical realization in all but exceptional instances. The values for permissible noise field deduced by Mr. Forrest from the paper will require to be reduced by a number m, representing the degree of modulation of the signal carrier in the manner already explained. This circumstance, of course, lends additional support to his contention that serious interference will be experienced immediately beneath the high-tension transmission line dealt with in Table 2. Whilst agreeing with this contention, it should be pointed out that at $\frac{1}{4}$ mile from the line the 2 000-metre noise field has diminished by some 30 decibels and the 20-metre noise field by some 20 decibels, and that in consequence the standards recommended in the paper as representative of essentially interference-free conditions would in fact be approximately realized at such a distance from the line in question. There is no reason to suppose that the values given in Table 2 include noise due to another source; attenuation/distance measurements, made at the time of these tests, quite discount the

Signal and Noise Field Values for Communication Services.

	Long-distance telephony services	
	Long-wave	Short-wave
	Decibels relative to 1 μV/m	
Average signal field	20	26
Minimum operating signal field..	0	2
Average noise field	—	6·5
Average range of noise field .	10 to 30	— 1 to 14

suggestion. In regard to the figure of 166 μV per metre which Mr. Forrest refers to as "the proposed French figure," if he suggests that it should be considered as a basis for interference suppression work in this country then it is very desirable to point out that the figure has not been accepted by the French Post Office, neither has it any statutory backing whatever in France. It is agreed that radio interference is not the primary consideration in the design of a h.t. overhead system. Nevertheless attention can be given to it without deleteriously affecting the main object of the design. Current literature, in fact, indicates that the contrary effect is achieved by designs which ensure increased radio-interference corona voltages. Wireless relay systems are not free from interference troubles. If the reference to these systems is intended to convey the suggestion that the question of radio interference should be resolved by general recourse to them, then perhaps it should be stated that their popularity is such that the subscribers to these systems constitute only a small percentage of the total number of broadcasting listeners. I am rather averse to quoting figures which purport to represent either the extent of, or an analysis of, complaints of reception from listeners. Such figures can be very misleading. It can be said in regard to faults, however, that faults in radio receivers, in house and distribution wiring and cables, as well as in overhead transmission lines, are at times responsible for poor reception conditions.

It is interesting to receive Prof. Fortescue's confirmation of the concluding sentence of the paper. In regard to his reference to the arc it may be stated that experience shows that the more sudden the collapse, the greater is the interference; long-drawn-out arcs in heavy-current circuits produce less interference than the shorter-period sparks of small-current circuits. An example of this is to be found in the trolley-bus. If the trolley arm is jerked from the overhead conductors when the bus is standing with only its lighting circuits switched on, the interference is much greater than if the similar operation is performed when the bus is running with the traction motors in action. Furthermore, in the case of essentially sparklessly commutating motors, in which the spark is minute and of short duration, the interference may, for the same reason, be very intense. Mr. L. B. Turner has also referred to this matter, and his calculation, which suggests that the breaking of a circuit is more troublesome in the matter of radio interference than the making of a circuit, is certainly borne out in practice. As indicated above, a very short-duration spark gives much more interference than a long-drawn-out arc, which latter may accordingly be regarded as an alleviating circumstance in the breaking of an electric circuit.

Referring to Mr. Bishop's remarks, it is quite true that all radio communication services are concerned in the question of radio interference, and that, in addition to the B.B.C., other authorities, such as the naval, military, air, and police, as well as the General Post Office, are interested. Mr. Bishop's brief survey of the question is interesting and I am obliged to him for his supporting data relative to Mr. Donaldson's remarks that in the aggregate the radio load is not an insignificant one. Furthermore, in assessing the value of this load to the undertakings it must not be lost sight of that customers actually purchase many times this amount for other domestic purposes and that their numbers are liable to be increased by an amelioration of the existing radio-interference conditions. A census which has recently been compiled by an undertaking supplying over 10 000 customers, disclosed the fact that 27·82 per cent of the customers' premises were equipped with all-mains-operated sets, 13·55 per cent with h.t. eliminator and l.t. accumulator-operated sets, and 7·35 per cent with battery-operated sets.

The explanation given by Mr. Wynn of the main considerations which lead to the figure of 40 decibels as the desirable objective for the signal/noise ratio is very informative. He points out that in the comparable case of Post Office trunk lines, the noise-level on such circuits is more than 50 decibels below the transmitted programme. Actually for international cable circuits a signal/noise ratio of at least 55 decibels is required, and in order to achieve this overall result on such circuits the noise on the actual lines is arranged, by special cable-balancing operations, to be very considerably below this level. Mr. Wynn also points out the necessity for the recommendations which have been

made in the paper in regard to the minimum field strength to be protected. Perhaps with the desire to be as conciliatory as possible, he suggested that in respect of the short and ultra-short wavelengths the recommended standard may be regarded as somewhat high. Without wishing to be one whit less reasonable in regard to the requirements of the matter, I should like to emphasize that the Post Office radiotelephony services are capable of working on fields of zero and of 2 decibels, relative to 1 μV per metre, for long-wave and short-wave circuits respectively, under favourable noise conditions, and that unless such fields are protected from noise to a reasonable degree, valuable traffic time will be lost to such services. Mr. Wynn emphasizes a matter which has been dealt with in the earlier portion of this reply, namely the needs of the electrical manufacturer in the matter of standards of suppression. There is no doubt whatever that this need is urgent; in fact the present-day attitude of manufacturers to requests for the suppression of interference may be summed up in the words "if you can tell me exactly what you want, I will try to give it to you."

Amongst other matters, Col. Angwin has referred to the fact that a number of European countries have been driven into legislation on this subject. Without doubt, the indications are that such legislation has been hastily conceived, since in no case have technical data, governing the degree of suppression to be achieved, been embodied in the decrees. As a consequence it is considered that the administration of such decrees will prove very unsatisfactory. Col. Angwin has also pointed out what may be regarded as a fortuitous feature of the interference from electrical plant on short waves, namely, that in general such interference is at a lower level than that on the longer waves. In regard to the ultra-short waves, the future of television as well as that of short telephony links for inland purposes and for the spanning of estuaries and narrow seas lies with their development. Difficulties are already being experienced in such development by reason of the interference from spark ignition systems.

Mr. Haswell's statement that commutation is an important factor in the interference from d.c. motors is agreed. The type of brush as well as its adjustment will certainly also influence the results. Interference may exist, however, even with seemingly sparkless commutation, and at times to a much greater degree than under serious sparking conditions. Mr. Haswell's observations on the audio-frequency sympathy between an electric motor and a radio receiver are interesting. The effect which he has noted, however, may be ascribed solely to the reaction of the mechanical load on the motor upon the flow of current in its electrical circuits. In many cases such reaction would be rhythmic and would certainly be so in the case of the pump motor which Mr. Haswell quotes.

It has been stated in the paper that if the aerial is located in an interfering field, nothing can be done at the receiver to alleviate the effects of such a field. Mr. L. B. Turner has emphasized this fundamental feature, and, since the fact is so frequently questioned, his remarks thereon are very apposite to the subject of the paper. Mr. Turner also agrees that if progress is to be made towards a settlement of the question, measurements must be made. He is, however, critical, and perhaps justly so from a strictly scientific point of view, of some of the engineering means which have been suggested in the paper and discussed during the meeting. In the earlier part of this reply certain features of the paper have been amplified. It is hoped, therefore, that the additional explanation which has been given will commend the suggestions which are put forward as a practical technical basis in dealing with this subject.

Mr. Floyd is quite correct when he says that radio interference is not confined to faulty plant but may arise from a machine which is functioning normally. The statements leading to the conclusion that radio interference should be dealt with *in situ* and not in the factory are thought not to be generally sound. In regard to the conclusion it may be said that the present-day irresponsibility in regard to the suppression of interference arises mainly because electrical plant is sold in an interfering condition.

The correctness of Mr. Bailey's argument is agreed. The expression for noise field in terms of signal field, signal/noise ratio, and degree of modulation of signal carrier, which has now been given, perhaps cover Mr. Bailey's remarks. Mr. Bailey has made a slip in expressing a 30 per cent modulation as 6 decibels; the value should be approximately 10·5 decibels.

The point raised by Dr. Hughes at the beginning of his remarks is of great importance. It relates to the determination of the true signal/noise ratio of a radio transmission subjected to noise. It has been dealt with in the earlier part of this reply, in which it is shown how a discrepancy of n decibels may arise in such determination. The magnitude of n may be as much as 15 in some cases. Calculations of the upper limit of permissible radio noise field, which involved this discrepancy, would accordingly be some 15 decibels high. Dr. Hughes's description of the methods of measurement employed for the determination of the speech/noise ratios of microphone and of broadcast receiver outputs is very interesting. He has commented upon the gramophonic demonstration from the point of view of the audio response of the instrument. Since a high-class commercial instrument was employed, it is presumed that the contention is that the average listener's reproducing conditions were not sufficiently closely simulated. This is true, but it is considered that the discrepancy does not seriously invalidate the approximate quantitative conclusions which may be arrived at from the demonstration.

In reply to Mr. Kennedy, it should be stated at once that the demonstration aimed at conveying an idea of the character of the noises introduced into a radio transmission by the operation of electrical plant. The level of the noises was purposely increased not only for this purpose but also for the purpose of demonstrating the effectiveness of the suppression devices. Mr. Kennedy's freedom from interference is possibly due to his motors being of the a.c. induction type and it is also likely that he quite properly regards as innocuous the occasional or intermittent interference from switches of the hand-operated or electrically-operated type. In any case inspection would disclose the reasons. Actually

telephone switching apparatus is referred to in the paper under Class B interfering plant. Such interference can be suppressed and, although it is of but occasional character, the Post Office deals with all justifiable cases of complaint arising under this head.

In reply to Mr. Swift, a radio receiver operating from an aerial located in an interfering field is not greatly immunized from noise by improvement of its selectivity. With regard to trolley-buses, the trouble lies with the overhead network which radiates the interference produced by the bus and power-station equipment. It is thought that the insulation from ground of the vehicles does not materially affect the position; some tramway systems give rise to severe interference.

In reply to Mr. Braendle, the small radio accessory motor finds a place in Class A (ii) plant. The interference from such items when literally embodied in the receiving equipment will of course be considerable. Exactly the same simple principles of suppression as have been described in the paper may be successfully employed. Complete screening of the machine and its supply leads should be effective. In this case it is also the preferable cure. Alternatively, multiple-unit suppressors will be needed in order to obtain suppression to the desired degree. In this connection the inductance inherently associated with the condensers, and particularly the inductance of connecting leads, will require to be controlled, especially for the purpose of ensuring suppression of the highest frequencies. In general, it will be found advantageous to use condensers of small capacitance. Radiation from connecting leads, which will require to be as short as possible, must also be controlled. The data which Mr. Braendle has requested cover a wide field and it is regretted that complete information is not available. However, in regard to (1) the interfering fields in the immediate neighbourhood of an electrical item are very complex and do not obey the laws of radiation; it is doubtful whether accurate measurements are possible. In regard to (2) and (4), the interfering spectrum is governed not only by the design of the machine, regarded as a radio-frequency generator, but also by the electrical characteristics of the supply system. In regard to (3), the question is too general to permit of a specific reply. It is very likely, however, that variations in the character of the high-frequency portion of the spectrum will be considerably influenced by the manufacturing tolerances normal to any particular type. The variations due to supply mains could be entirely eliminated by a suitably designed mains terminating network, located between the mains and the electrical item.

Mr. Friedman's remarks on ultra-short waves and ignition systems are interesting. It is because of the difficulties which he enumerates that the recommended value of protected field strength for waves below 20 metres is as low as 10 μV per metre. Mr. Friedman's second point is covered in the reply to Mr. Kennedy.

Mr. Lett has emphasized the value of screened receivers and screened aerial transmission systems. With such means, however, complete elimination cannot be effected unless the aerial is placed outside the field of interference. In regard to the use of low-frequency cut-off, deterioration of the receiver fidelity is hardly the solution of the interference question. The quality required for satisfactory loud-speaker reproduction is vastly superior to that provided on commercial telephonic systems. The numerical example given is not very conclusive. With a static level of 100 μV per metre, as quoted, a signal/noise ratio of about 10 decibels would be obtained on a signal field of 1 mV per metre, modulated 32 per cent. Very considerable modification of the fidelity of the receiver would be required to deal with this condition.

Mr. Scroggie's remarks have been dealt with in the earlier portion of this reply. It is hoped that the figures given in the paper will thereby be made more intelligible to him.